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AN ESTIMATE OF GERMAN STOCKS OF EXPLOSIVES

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An Estimate of German Stocks of Explosives

The German explosive position may be analyzed in terms of the availability of two raw materials: toluene and sulphuric acid. Such an analysis suggests that from 1935 up to the outbreak of the war, there was sufficient sulphuric acid available to have permitted the manufacture of almost 3 times as many tons of propellants as TNT. Germany's future propellant position is limited, if at all, by existing plant capacity. Germany had sufficient toluene over and above industrial consumption to have had TNT stocks amounting to about 230,000 metric tons at the outbreak of the war. This stock position was possibly increased to 400,000 metric tons at the time of the outbreak of the Russian war, but by January, 1942, the needs of that campaign probably had lowered German stocks to the immediate prewar position. If consumption on the Russian front in 1942 were to equal that of 1941, German stocks of TNT would be reduced dangerously low. It is possible that Germany's limited supply of TNT has been a factor contributing to the reduction of the scale of activity in Russia from 3 fronts in 1941 to 1 in 1942.

I

The Prewar Position: Toluene and T.N.T.

Toluene, the basic ingredient in T.N.T., is principally obtained from benzol[1], a by-product of the coking industry. Minor amounts of toluene are obtained from the low-temperature carbonization plants used in the manufacture of municipal gas, and, at present, some toluene may be manufactured synthetically from petroleum.

The amount of benzol recovered as a by-product is dependent upon the efficiency of the equipment used, the temperature at which the coking is done, and the volatile content of the coals used. Thus, for prewar Axis Europe, the benzol recovery ranged from approximately 1 percent of the coal coked (Poland, 1937) to .57 percent (Holland, 1937). In Germany, benzol recovery from coking plants rose from .864 percent (1935) to .962 percent in 1937; an increase due, in part, to the acquisition of the Saar coals and also to a determined effort to increase the light oil yield.

1/ The term benzol is used synonomously with light oil, which, according to "The Composition of Coal Tar and Light Oil" (Bureau of Mines, Bull. 412, p.3), is "a mobile liquid that distills over a relatively low temperature range and has the lowest density of the various tar distillates."

Toluene recovery in Germany increased from 6.8 percent of the benzol in 1935 to 8.3 percent in 1937. This recovery was far below the theoretical maximum of 20 percent1/ Toluene recovery undoubtedly rose substantially in the ensuing years. In April, 1937, a decree made it compulsory to extract all toluene from benzol. It is not likely that, even now, the theoretical maximum is recovered, and it may be assumed that the actual recovery from high-temperature coking operations attained only 17 percent in 1942.

1/ A theoretical maximum of 20 percent is based on the following evidence:

1) The average toluene recovery for 19 American coals is 19.8 percent of the "light oil recovery" ("Composition of Coal Tar and Light Oil," Bureau of Mines Bull. 412, p.6) at coking temperatures at 1000° C.

2) According to Dr. A. C. Fieldner, Chief, Fuels and Explosives Service, Bureau of Mines, German coals are at least as volatile as are American coals and the toluene recovery should be as great, or greater than, the theoretical maximum of American coals.

3) The theoretical recovery of toluene is about 20 percent, according to Mr. Otto Rosenthal, long connected with the Chemacid concern which dealt with the European benzol industry.

Similarly, toluene recovery from municipal gas plants in all probability has not reached the theoretical maximum of about 14 percent, but is at present approximately 10 percent of the recovered light oil.

German output of toluene may be estimated:

Probable German Output of Toluene

(Thousand metric tons)

	1935	1936	1937	1938	1939 1/	1940 1/	1941 1/	1942 1/
Toluene: As percent of benzol.....	6.8	7.7	8.3	10	12	14	16	17
Toluene: output.....	24.0	33.0	44.0	57	77	96	114	120

1/ Includes Austria and Czechoslovakia.

As nearly half a ton of toluene is required to manufacture a ton of T.N.T., the potential explosive output can be easily determined. First, however, the amount used for purposes other than explosives must be deducted:

1) In prewar times, industrial use of toluene amounted to 10-15,000 tons per year. These industrial demands are assumed to have remained relatively constant at, say, 14,000 tons per year.

2) Military uses of toluene for fuel were probably small. Toluene is used in some high octane gasolenes, especially in winter to lower the freezing point of benzene. Consumption for this purpose might amount to as much as 30,000 tons during the present year[1], but it was probably much smaller in prewar years.

Aviation Consumption of Toluene

(Thousand Metric Tons)

1935	1936	1937	1938	1939	1940	1941	1942
..	..	1	2	5	10	20	30

Estimated Toluene Available to Explosives Industry

(Thousand Metric Tons)

	1935	1936	1937	1938	1939[2]	1940[2]	1941[2]	1942[2]
Total toluene	24	33	44	57	77	96	114	120
Less:								
1) industrial uses	14	14	14	14	14	14	14	14
2) used as fuel	..	1	2	5	10	20	30	
Toluene available for explosives	10	19	29	41	58	72	80	76
Estimated TNT output[3]	20	38	58	82	116	144	160	152

1/ This figure is based on an analysis of some 80 German fuels and suggests that toluene may, on the average, be 1 percent of the total fuel, a figure we assume to be 3 million metric tons at the maximum.

2/ Includes Austria and Czechoslovakia.

3/ Estimated at twice the available toluene.

Consumption of high explosives by the German army in training in prewar years was undoubtedly quite low, because of the use of blank cartridges, sand-filled bombs, etc. If we assume there were, on the average, 40 divisions training in Germany from 1935 to 1939, and that each consumed, say, 10 tons of ammunition per day[1] annual consumption of ammunition would be 146,000 tons. In actual fighting high explosives constitute about 8 percent of the weight of ammunition. If, during training, we assume HE expenditure to be half of wartime expenditure, or 4 percent, we get about 6000 tons per year, or 30,000 tons for the 5 prewar years under consideration.

Total prewar stocks of T.N.T. in Germany may thus have been:

1935	20,000 tons	
1936	38,000	
1937	58,000	
1938	82,000	
1939 (2/3yr.)	77,000	
	265,000 tons	- Total T.N.T. produced,
less	30,000 "	- Consumed in training
	235,000 tons, say, 230,000 metric tons T.N.T. stock.	

1/ Roughly 10 percent of the estimated consumption on the Eastern Front.

The War Years: Toluene and T.N.T.

The toluene available for T.N.T. in Greater Germany since the outbreak of the war is shown in the tables on page 5. From the potential amount of T.N.T. available from September 1939 to June 30, 1941, namely, 260,000[1] tons, deductions must be made for the various campaigns Germany had undertaken in the period, and, as a compensating factor, the additional sources of toluene made available through conquest must be added.

(1) If one assumes that in Poland 82 divisions each consumed 125 tons of ammunition per day, or, roughly, 10 tons of T.N.T. per day for the 19-day campaign, T.N.T. expenditure would have amounted to about 10,000 tons.

(2) If the same daily consumption rate applied to the campaign in the West, and if it is assumed 150 divisions were engaged for 46 days, about 40,000 tons of T.N.T. would be accounted for.

(3) During the 93 weeks preceding the outbreak of the war with Russia, it is unlikely that, on an average, much over 300 tons per week of T.N.T. was expended by the German Air Force, say, about 30,000 tons of T.N.T. in all.

(4) An additional 20,000 tons was consumed during this period in training and in the Balkans and Libyan campaigns.

1/ Derived from the table on page 5 by taking the 1940 output plus 1/3 the 1939 output, and 1/2 the 1941 production - 263,000 tons, say, 260,000 tons.

These categories account for a consumption of 100,000 tons of TNT, leaving 160,000 tons for potential accumulation to stocks during this period. To this amount must be added the TNT Germany might have obtained from the toluene of Occupied Europe.

Estimated Toluene Production: Occupied Europe

(Thousand Metric Tons)

	1940	1941 (½ year)
Poland	2	3
Holland	.	2
Belgium	.	4
France	.	4
Total	2	13

The total contribution of occupied countries would thus be 15,000 metric tons of toluene, or 30,000 tons of potential TNT, thus raising the addition to Germany's stocks to 190,000 metric tons. Thus, at the outbreak of the Russian campaign, Germany's stocks may have been:

230,000
+ 190,000
420,000 tons of TNT.

As is suggested in E.D. #35, ("The OSS and MEW Estimates of German High Explosives Consumption and Production"), HE consumption during the last half of 1941 was

about 330,000 tons. This figure does not refer solely to TNT as undoubtedly some amatol was consumed in German artillery ammunition, while aerial bombs contain varying TNT wax mixtures. It may be assumed that 300,000 tons of the above amount were TNT. Only partially offsetting this rate of TNT consumption is the production of toluene during the last half of 1941. This is estimated at:

Greater Germany	40,000	metric tons of toluene
Dominated Europe	14,000	" " " "
	54,000	" " potential supply of approximately 100,000 tons of TNT.

From these figures, an estimate of stocks on hand at the beginning of 1942 may be derived:

Estimated German TNT Stocks Jan. 1, 1942

	420,000 tons	on hand, June 22, 1941
plus	100,000 "	production, June 22-Dec.31, 1941.
	520,000 tons	
less	300,000 "	estimated consumption of TNT, June 22-Dec. 31, 1941.
	220,000 tons	Stocks on hand January 1, 1942.

It therefore appears that German stocks of TNT at the beginning of 1942 were approximately the same as at the outbreak of the war in 1939.

II

The Prewar Position of Sulphuric Acid

The variety of industrial uses of sulphuric acid does not permit a precise estimation of the amount consumed by the explosives industry. In Table II, a theoretical supply-demand pattern for Germany in prewar years and for 1942 is shown[1]. Admittedly this table contains many errors. For example, it is almost certain that the amount of acid used in the manufacture of superphosphates is less than that shown in Table II, the reason being that 60° Bé acid is probably used rather than the 67° Bé acid assumed in our calculations. Again, various reports suggest relatively large savings of acid in the rayon industry in recent years. These have not been taken into consideration. The figures in the last column, "Unallocated," are arbitrarily assumed; the amount for 1938 (50,000 tons of sulphur content) being the estimate of the MEW[2] for that year.

It thus appears that the figures allocated to the explosives industry are subject to considerable latitude;

1/ The methodology used in making these estimates can be found in detail in Economics Division internal memo I.R. 37-A, "Sulphuric Acid."

2/ MEW "Sulphuric Acid: German and Occupied Europe" 1/1/42.

these figures, however, in all probability represent the minimum amounts available to this industry.

If we convert the figures allocated to explosives from sulphur content to acid, we get:

Probable Consumption of Sulphuric Acid by the German Explosives Industry

(Thousand Metric Tons)

Sulphuric Acid	1935	1936	1937	1938	1939	1940	1941	1942
(Sulphur Content)	28	57	93	113	197	(209 1/)	(220 1/)	231
(100%)	91	186	303	369	643	682	718	754

1/ Interpolated.

The amount of sulphuric acid used in the manufacture of explosives varies with the efficiency of the plant, the type of explosive manufactured, etc. An extremely generous allowance would be one ton of acid per ton of explosive manufactured. Assuming this, an estimate must first be made of the production of commercial explosives. This is extremely difficult to do, since the production is dependent, not only on the amount of mining, quarrying and construction work, but also on the relative amounts of black powder and high explosives used. By comparing 1938 German mineral output with U.S. production and explosive consumption, we get:

1938 U. S. Consumption of Commercial Explosives by Industry; And an Estimate of the Comparable German Position

(Thousand Metric Tons)

	United States			Germany		
		Explosives			Estimated Explosives	
	Production	Black Powder	HE	Production	Black Powder	HE
Coal.....	384,000	23	33	186,000	12	16
Metals and others.	1,870	2	107	1,076	..	62
TOTAL		25	140		12	78

Or, for the entire period:

Probable German Consumption of Commercial Explosives by Industry

(Thousand Metric Tons)

Year	Coal		Metals & Others		Estimated Total HE
	Production	Estimated HE Consumed	Output	Estimated HE Consumed	
1935	143,000	12	721	42	54
1936	158,000	14	749	43	57
1937	184,000	16	1000	58	74
1938	186,000	16	1076	62	78
1939	200,000	17	1100?	64?	81
1940	.....	..	....	..	(90)
1941	.....	..	....	..	(100)
1942	.....	..	....	..	(100)

Net exports of all explosives, ammunition, etc., in 1938 averaged 1000 tons per month. If half of this consisted of HE, an additional 6000 tons must be added to our estimate of consumption in 1938. If this estimate held for the other prewar years, we would get:

Possible German Production of Commercial Explosives

(Thousand Metric Tons)

	1935	1936	1937	1938	1939
Estimated consumption of commercial explosives..	54	57	74	78	81
Estimated exports..	6	6	6	6	6
Estimated production commercial explosives.....	60	63	80	84	89

By subtraction of the sulphuric acid consumed in the production of TNT and commercial explosives from the total amount available for explosives, we get:

Estimated Sulphuric Acid Available for German Propellants

(Thousand Metric Tons)

Year	Available Sulphuric Acid	Less Commercial Explosive Consumption	Less Consumption in TNT	Available for Propellants	Ratio of Propellants: TNT
1935	91	60	20	11	1.0 : 1.8
1936	186	63	36	87	2.3 : 1.0
1937	303	80	58	165	2.8 : 1.0
1938	369	84	82	203	2.5 : 1.0
1939	643	89	116	438	3.8 : 1.0
1940 (est.)	682	90[1]	144	448	3.2 : 1.0
1941 (est.)	718	100[1]	160	458	2.9 : 1.0
1942 (est.)	784	100[1]	182	502	3.3 : 1.0

1/ Assumes no exports.

The ratios shown in the last column above are interesting. If 1) consumption of TNT by the Luftwaffe is is about 10 percent of the total TNT consumed 1/, and

1/ Both British and American estimates of German ammunition consumption on the Eastern Front suggest this.

2) if consumption of propellants by ground forces in battle is roughly twice that of HE[1], it would appear that Germany from 1936 on had sulphuric acid to produce more than enough propellants for her TNT output. Prewar supply of propellants, 1938-39, would have been enormous, more than 750,000 metric tons, if all the available acid went into their manufacture. Consumption of propellants by the German army in training, 1938-39, would amount to roughly 4 times the consumption of TNT - or 120,000 tons of propellants. Stocks at the outbreak of the war could therefore have been over 600,000 metric tons. This indicates that Germany would have little difficulty in balancing TNT with the necessary proportion of propellants.

The Sulphuric Acid Position: The War Years

There is, at present, no information on the amount of sulphuric acid available for explosives during 1940, 1941. If we interpolate between the 1939 and 1942 estimates (see Table on Page 11), it appears that about 1,000,000 tons of sulphuric acid were available for the manufacture of an equal amount of propellants during the war up to January 1, 1942[2].

1/ In general, propellants average about 16 percent the total weight of a shell; HE about 8 percent.

2/ 1939 (4 months)--148,000 metric tons; 1940--448,000 metric tons; 1941--458,000 metric tons.

Consumption up to the beginning of 1942 can be estimated roughly by doubling the assumed consumption of TNT by ground forces:

	(Thousand Metric Tons)
Poland	20
West	80
Russia (1941)	600
Other	40
Total	740

Wartime production of propellants could therefore have been more than sufficient to meet wartime consumption, so far as the supply of sulphuric acid is concerned. Recent reports of the reopening of French nitro-cellulose plants indicate, however, that German production of propellants may be pressing against the capacity of processing facilities.

III

S U M M A R Y

The German TNT position may become critical if the 1942 Russian campaign consumes AK at the same rate as is estimated for 1941. This potential shortage is reflected in British analyses of German bombs which have shown

progressively decreasing amounts of TNT, relative to the total HE content[1]. In addition, this shortage may possibly be one of the contributing causes of the lowered over-all intensity of warfare on the Eastern Front this year. Instead of an all-out campaign on three fronts, the Germans have thus far concentrated their chief efforts in the south.

On the other hand, before TNT became a really critical factor, the Germans could use amatol to a far greater extent than they apparently have to date. Germany could easily produce sufficient ammonium nitrate to meet any demands of the explosives industry.

1/ "Report on Visit to C.S.R.D. Ordnance Board," Shrewsbury. Dr. Phelps, MEW.

TABLE I

An Estimate of the German Sulphuric Acid Position, 1935-1942

(Thousand Metric Tons of S Content)

Year	PRODUCTION			CONSUMPTION										
	Production	Net Imports	Total	Super-Phosphates	Amm. Sulphate	Other Nitrogenous Fertiliser	Dyes	Other Sulphates	Rayon	Metals	Refineries	Earths & Pigments	Explosives	Unallocated
1935	514	30(est)	534	155	116	43	43	66	20	22	11	10	28	20
1936	576	30(est)	606	160	113	46	40	62	37	29	16	11	57	30
1937	670	33	703	165	121	41	45	75	65	30	17	13	93	40
1938	800	36	836	178 1/	160	46 1/	46 1/	80 1/	89	32	18 1/	14 1/	188	50
1939	947	30 1/	977	196 1/	160	47 1/	46 1/	80 1/	114	35	18 1/	14 1/	197	60
1940	...	..	...	...	...	..	..	..	...	..	..	..	(209)	..
1941	...	..	...	...	...	..	..	..	...	..	..	..	(220)	..
1942(est.)	1000?	-2 1/	998	97	90	30	45	70	286	34	10	15	231	90

1/ Interpolated data.